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Effect of some physical and geometrical parametres on photonic band gap (PBGs) materiels

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Abstract: In this study, we have examined the impact of specific geometric (period, radius) and physical (refractive index) parameters on the properties of forbidden bands. Our focus was on two-dimensional photonic crystals composed of triangular and square structures made of Si, Ge, and GaAs rods in an air medium. The results demonstrate that increasing the refractive index of the materials relative to the substrate, as well as adjusting the geometric parameters, leads to a wider band gap. Furthermore, the open bands shift towards higher wavelengths. Simulation results obtained using Band Solve and Full Wave methods revealed that variations in the forbidden bands follow a Gaussian curve, with a maximum band occurring around 1.55 µm for r=0.24 µm and a=0.4 µm. Additionally, a linear decrease in the width of the band gap was observed with changes in the physical parameters.

Keywords: Photonic crystal (PhC); Photonic band gap (PBG); transverse electric (TE); refractive index (RI); form factor (FF).

Résumé : Dans cette étude, nous avons étudié l'influence simulée de certains paramètres géométriques (période, rayon) et physiques (indice de réfraction) sur les caractéristiques des bandes interdites. Les cristaux photoniques bidimensionnels étudiés dans ce travail sont des structures triangulaires et carrées composées de tiges de Si, Ge et GaAs immergées dans l'air. Il a été observé que l'augmentation de l'indice de réfraction des matériaux par rapport à celui du substrat, ainsi que les paramètres géométriques, augmentent la largeur de la bande interdite. De plus, les bandes ouvertes se déplacent vers des longueurs d'onde plus élevées. Les résultats des simulations des paramètres géométriques à l'aide des méthodes Band Solve et Full Wave ont également montré que les variations des bandes interdites suivent une courbe gaussienne, avec une bande maximale autour de 1,55 µm pour r = 0,24 µm et a = 0,4 µm. De plus, une diminution linéaire de la largeur de la bande interdite a été observée avec les variations des paramètres physiques.

Mots-clés : Cristal photonique (PhC) ; Bande interdite photonique (PBG) ; transverse électrique (TE) ; indice de réfraction (RI) ; facteur de forme (FF).

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1. INTRODUCTION

In recent ten years, The concept of Photonics Crystals have been developed rapidly and widely applied [1,2] Photonic Band Gap materials or photonic crystals are structures whose dielectric constant is periodically modulated. These materials have frequency bands for which the propagation of electromagnetic waves is prohibited. Like electrons in semiconductors, photons are distributed in transmission bands separated by interdit bands gap. This analogy allows it possible to envisage the use of photonic crystals as basic materials for the production of components for integrated optics. This artificial periodic structure has special photoelectric properties due to the existence of PBG [3,4]. It widely used in the design of solar cells because of their unique optical properties such as the photonic band gap and the "slow photon" effect[5],waveguides [6,7], reflectors [8], filters [9] and other devices. These dielectric structures can control the flow of light [10]. According to the spatial dimension, the research direction mainly includes one-dimensional photonic crystal [11], two-dimensional photonic crystal [12] and three-dimensional photonic crystal [13]. The results obtained on PhC devices based on semiconductors are very promising for applications in photonic crystals and their integrated circuits. The performance of the devices is mainly based on the focusing of the light thanks to the photonic band gap effects.[14]. likewise, the aim of the photonic crystal study is to improve the width of the photonic band gap. Whenever the band-gap of the PhC is bigger, the structure has high performance. The symmetry of the structure is essential to control the photonic band gap (PBG) [15].The properties of the structures are simulated using the plane wave expansion (PWE) method integrated in the algorithm (RSoft Photonic).[16]

In this work, a comparative study was carried out for different materials such as Si, Ge, and GaAs in order to study the effect of physical and geometrical properties. So, we will manipulate on the fundamental and important factors taking into consideration their main relationship with the variation of the length of the range parameters in order to find adequate values to obtain high quality photonic structures, The photonic crystal is the image of the semi-conducteur in the optical field,the similarity between the mis the band gap,which is the thing that caused a huge technological revolution and great use,the aim of this work was to develop the width of this gap in order to expand and improve its use

2. STRUCTURE DESIGN

Photonic crystals (PhC) are periodic dielectric material with the capability to control and manipulate light propagation. Fig.1 shows the most important characteristics of optical crystals. The host structure of PhC, 2D triangular lattices, consisting of rods in air with radius r= 0.24µm, period a=0.4µm and size of photonic crystal is 21×21. In this work,we fixed the value of the period (a) because we noticed during changing it that it does not affect PBG and we played on the radius starting from its lowest value,which is the point of disappearance PBG to the largest value,which is the the point of the imposibility of designing the shape to overlap it,througt which we obtained the largest PBG i took it as a reference and use dit in the next design.

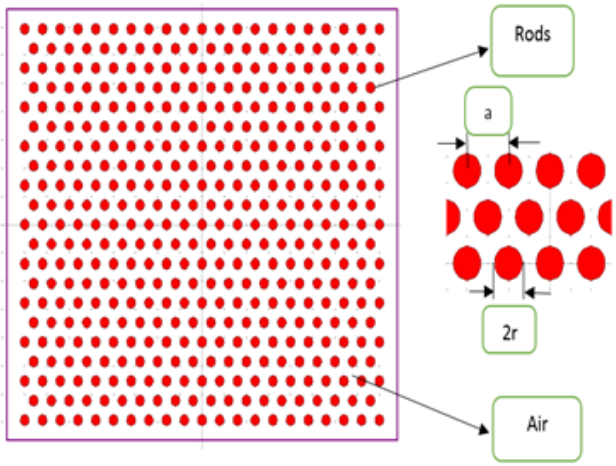

Fig. 1. Design of 2D triangular photonic crystal.

In fig.2, we present the dispersion curves and band-gap for TE polarisations for the 2D rods in air having a large band-gap in the wavelength range of (1160.83 nm to 1847.83nm). It has been calculated along the Γ-M-K-Γ edge for the brillouin zone which is calculated by the PWE method of Band-Solve software.

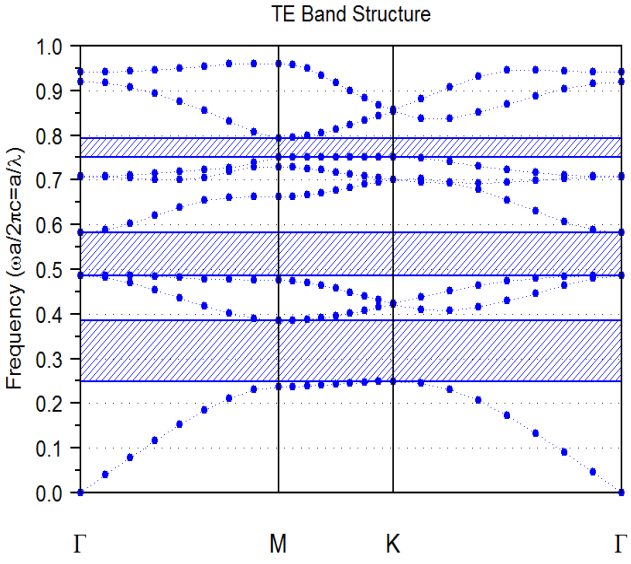

Fig. 2.The dispersion curves and band-gap for TE polarisations.

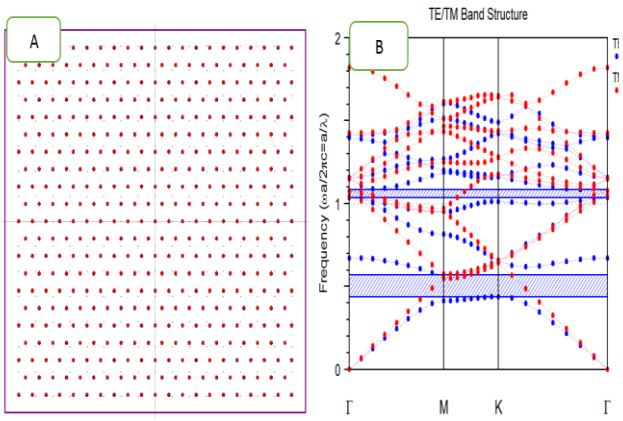

Fig.3. (A) is the design of PhC and (B) is the dispersion curves and band-gap for TE polarisations with radius r= 0.09µm, period a=0.4µm.

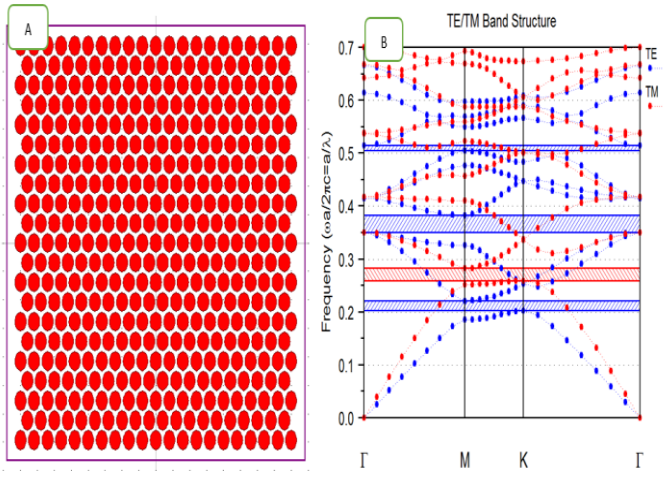

Fig. 4. (A) is the design of PhC and (B) is the dispersion curves and band-gap for TE polarisations with radius r= 0.42µm, period a=0.4µm.

In fig.3 (A) and fig.4 (A), we present the structure of PhC with different radius r=0.09 and r=0.42 respectively. It can be observed from fig.3 (B) and fig.4 (B) that the width band-gap varied with the variation of the form factor.

3. NUMERICAL SIMULATION AND ANALYSIS

In fig.5 below, a comparative study was made on three materials with different refractive index extended in the area (disconnected structure) such as silicon (n_Si=3.42), germanium (n_Ge= 4), gallium arsenide (n_GaAS = 3,3); and various topologies such as triangular and square forms. We can notice from the obtained results of fig.5 that a Gausian variation in the width band-gap as a function of the variation in the form factor (It is a percentage that represents the value of the radius dividing the period r/a),the change in the geometrical characteristics has a clear effect on the extent and amount of light guidance, which in turne has a direct effect on the length of the gap and its borders in all results.

Mohamed elfateh hathat et all [17] they reached a gap value 975.6 to 1600.66nm represents width 625.6nm, merzouk ammari et all [18] 1435.3 to 1778 nm represents width 324.7 nm, F.Mehdizadeh et all [19] 1310 to 1774 nm represents width 464 nm.

And we, in turn, got it the best acquired form factor was FF=0.24 which was given by triangular germanium with the band-gap of 700 nm.

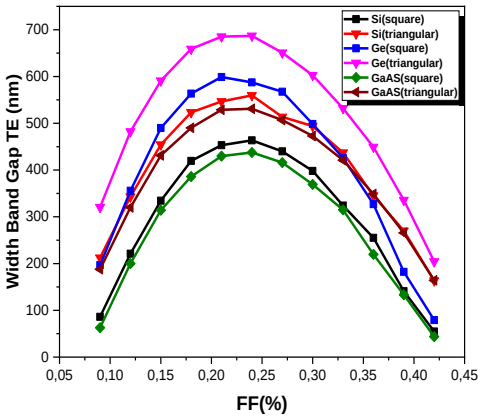

Fig. 5. The variation of the width band-gap for several materials as a function of form factor.

According to fig.6, a decreasing linear variation of the width PBG with the rise of the refractive index was observed for all materials. It can be seen that a high value of the width PBG was given by the triangular germanium. We can say that the triangular germanium is a suitable element for various applications such as photonic crystals, it is the result of reducing the difference in the refractive index between this middle reduction change the angle and direction of light reflection, which in turn affects and changes the boundaries and length of the gap.

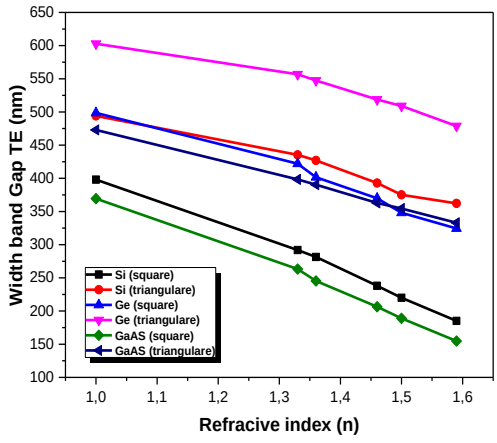

Fig. 6. The variation of the width band-gap as a function of refractive index.

Fig.7 presents the variation of the average PBG with the change of the refractive index. The acquired results summarized that the Si extended in the air (n=1) has a average PBG around of the telecommunication frequency in the order of 1550 nm The referece wavelength.

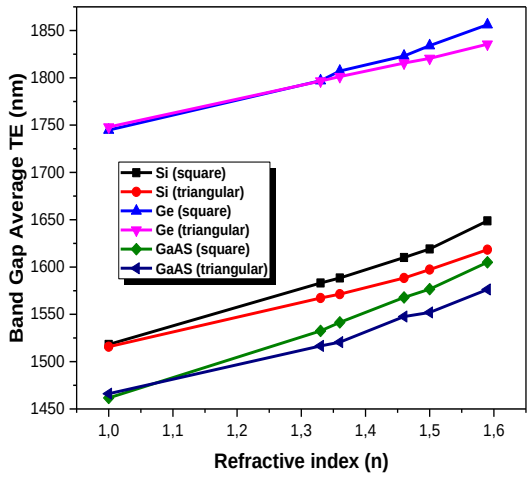

Fig. 7. The average band-gap as a function of refractive index.

From the results obtained previously from fig.7, we took the triangular silicium (Si = 3.42) as a structural support. Fig 8 shows the variation of width band-gap as a function of the form factor for several refractive index (n = 1, n = 1.33, n = 1.36, n = 1.46, n = 1, 5, n=1.59). An inversely proportional relationship was observed for the decrease in width PBG with an increase in the n index.

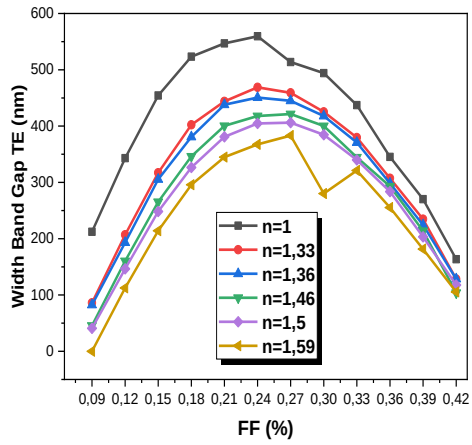

Fig. 8. The variation of the width band-gap of the Si triangular for different refractive index as a function of form factor.

The table below shows the most important parameters used in this work.

materials	Perid a (nm) fixed	Radius r (nm) chang	Type structure	Dimension	polaristion	reference wavelength
Ge,Si,GaAS	0.4	0.036 to 0.168	2D (squar, triangular)	21*21	TE	1550 nm

In this fig.9 we fixed the optimal values obtained above the disconnected structure,and we compared it with a different designe called in the field PhC the connected structure (holes in slab),we notice through it that it does not contain a gap for a small FF less than 18,and that it has a larger gap for an FF greater than 33,and it also distinguishes it from the TM polarization,unlike the first design.

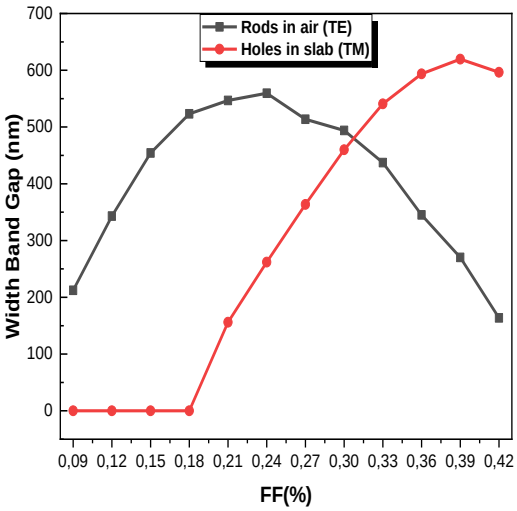

Fig. 9. The variation of the width band-gap of the Si triangular a function of form factor for two different designs rods In air and holes in slab.

4. Conclusion

In our study, a comparative study made for different materials in order to find adequate values to achieve high quality photonic structures. We studied the influence of geometric (FF) and physical (RI) parameters for different materials (Si, Ge and GaAS). The widest band-gap was observed for a form factor (FF) of 0.24 for triangular Ge.

The obtained results for the different models (square and triangular) of a 2D photonic crystal show a band-gap around the telecominication frequency of 1.55µm for the Si extended in the air. It is necessary to adjust the parameters to have good results and to choose the constituents of the crystal. It is also important to choose the topology of the PhC in particular the type and the form.

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